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FREE-OPERANT CHOICE BEHAVIOR: A MOLECULAR ANALYSIS

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Pigeons' pecks to two concurrent initial-link stimuli occasionally produced one of two mutually exclusive terminal links. Further responding to the terminal-link stimulus produced food under fixed-interval or fixed-ratio schedules. In such concurrent chained schedules, investigators rarely use a changeover delay to control superstitious switching, although it is customary to use a changeover delay in simple concurrent schedules in which choice responses produce food directly. When terminal-link fixed-interval schedules were equal or similar in duration and no changeover delay was employed, conditional probabilities of choice for a schedule were found to be lower if the last choice was for that schedule than if the last choice was for the other schedule ("switching dependency"). Imposition of a changeover delay with equal or unequal terminal links produced the opposite pattern: conditional probabilities of choice for a schedule were higher if the last choice was for that schedule than if the last choice was for the other schedule. Turning off all chamber lights during the changeover delay interval attenuated these "repetition dependencies." The results indicate that excessive switching can complicate the interpretation of data from concurrent chains much as from simple concurrent schedules, and that using blackouts to control switching may be preferable to using a changeover delay.

Key words: choice behavior, concurrent chained schedules, sequential patterning, changeover delay, interresponse time, key peck, pigeons

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Many of the variables that influence choice behavior have been studied with concurrent chained schedules of reinforcement (Autor, 1969). Under concurrent chained schedules, responses in the presence of two concurrent initial-link stimuli occasionally produce one of two stimuli associated with mutually exclusive terminal links. Further responding to the terminal-link stimulus produces food according to the schedule in that terminal link. Initial-link responses represent "choices" between terminal-link schedules, and investigators customarily express the organism's degree of preference for a schedule in terms of a "choice proportion"—the number of initial-link responses on one key divided by the number of initial-link responses on both keys.

With simple concurrent schedules in which concurrent performances directly produce primary reinforcement, there has been a long-standing assumption that superstitious switching between keys may develop if the response that produces food on one key is preceded by a response on the other key (Catania, 1966). To minimize superstitious switching, investigators usually employ a "changeover delay" with simple concurrent schedules, specifying that no response may produce reinforcement if the previous response was on the other key. Following a changeover, a period ensues during which further responding on the key cannot produce reinforcement. This procedure ensures that a delay of some minimum duration intervenes between the changeover and any subsequent reinforcement. The inclusion of a changeover delay typically decreases the frequency of changeover responses and increases the overall proportion of responses on the schedule providing the higher rate of reinforcement (e.g., Herrnstein, 1961).

In contrast to experiments involving simple concurrent schedules, experiments involving concurrent chains rarely include a changeover delay. No explicit rationale for this practice presently exists, a situation that could lead to ambiguities in the interpretation of choice data. For example, suppose that a model being

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tested fails to describe choice proportions adequately: theoretical values are more extreme than obtained values. In this case should the model be modified or should the experiment be repeated with a changeover delay? Or suppose that a changeover delay is used originally but the obtained values are more extreme than the theoretical values (e.g., Davison, 1969). Should the model be modified, or should the experiment be repeated without a changeover delay? Even when a model adequately describes choice proportions, problems of interpretation can arise from one's decision concerning use of a changeover delay, as studies with simple concurrent schedules illustrate. Although relative response rate usually "matches" relative reinforcement rate when a changeover delay is employed (deVilliers, 1977), matching has also been found without a changeover delay (e.g., Bradshaw, Szabadi, & Bevan, 1976; Heyman, 1979). Had investigators not employed a changeover delay in the former case or had they employed a changeover delay in the latter, their data might have been inconsistent with matching. Implicit in many studies which have found matching is the assumption that confirmation of this relationship justifies the procedural decision about a changeover delay, an assumption that is logically circular. What is needed is a method of determining whether the frequency of switching warrants inclusion of a changeover delay independently of one's theoretical expectations about choice proportions. The present study sought to develop such a procedure based upon sequential patterns of responding, a procedure applicable to simple concurrent schedules as well as to concurrent chains.

Four basic sequences comprise initial-link responding: repetitions on the left (L-L), changeovers from left to right (L-R), repetitions on the right (R-R), and changeovers from right to left (R-L). Conditional probabilities calculated from the frequencies (F) of these four sequences provide a useful overall index of sequential dependency. The fraction, $F_{L\text{-}L}/(F_{L\text{-}L} + F_{L\text{-}R})$, represents the probability of a peck on the left given that the last peck was on the left ($P_{L|L}$). The fraction, $F_{R\text{-}L}/(F_{R\text{-}L} + F_{R\text{-}R})$, represents the probability of a peck on the left given that the last peck was on the right ($P_{L|R}$). If choice behavior were free of sequential dependencies, the locus of the last peck would not be a source of variance and $P_{L|R}$ would equal $P_{L|L}$. A higher value of $P_{L|R}$ than of $P_{L|L}$ would indicate "excessive" switching between keys, while a higher value of $P_{L|L}$ would indicate excessive repetition of pecks on a key.

To clarify the manner in which such dependencies could come about, consider the hypothetical frequency distributions of changeovers and repetitions in Table 1. In each row there is a total of 100 pecks, 70 on the left key and 30 on the right. The choice proportion on the left key in each case is therefore .70, but, depending on the distribution of pecks among the four sequences, $P_{L|R}$ equals, exceeds, or falls below $P_{L|L}$. The difference, $P_{L|R} - P_{L|L}$, constitutes an index of the direction and magnitude of the dependencies, with a positive value representing a switching dependency and a negative value representing a repetition dependency. Two features of this "dependency index" may be noted. First, dependency index values do not necessarily vary with the absolute rate of switching or with overall response rates. If the number of sequences in Table 1 were multipled by 10, the rate of switching and the overall response rate would be increased, but the dependency index values would remain constant. Second, the index is intended as an ordinal measure; there is no implication that a dependency with a value of .20 is twice as "strong" as a dependency with a value of .10. Ordinal measurement is assumed because the precise quantitative relationship between dependency index values would be somewhat different if one calculated ratios of $P_{L|R}$ and $P_{L|L}$ instead of differences. For purposes of the present analysis, ordinal measurement was sufficient.

In Experiment 1, a fixed-interval (FI) 10-sec schedule was presented in one terminal link together with a series of FI schedules in the other terminal link, the durations of which ranged from 5 to 25 sec. For each pair of terminal-link schedules, $P_{L|R}$ and $P_{L|L}$ were compared. Lack of clear differences between $P_{L|R}$ and $P_{L|L}$ would be consistent with the practice of omitting a changeover delay in concurrent chained schedules. Positive values of the dependency index ($P_{L|R} > P_{L|L}$) would suggest that inclusion of a changeover delay might be appropriate.

Comparison of $P_{L|R}$ with $P_{L|L}$ would reveal whether choice varied with the location of the

Table 1

Hypothetical Frequency Distributions of Changeovers and Repetitions

Dependency	*L-L*	*L-R*	*R-L*	*R-R*	P_L	$P_{L\|R}$	$P_{L\|L}$	*Dependency index* ($P_{L\|R}$-$P_{L\|L}$)
None	49	21	21	9	.70	.70	.70	.00
Switching	42	28	28	2	.70	.93	.60	.33
Repetition	60	10	10	20	.70	.70	.86	−.16

previous peck, but would not indicate whether pecks preceding the last one were a source of variance. Experiments 2, 3, and 4 additionally examined choice as a function of the number of prior consecutive pecks on a key—$P_{L|XR}$ and $P_{L|XL}$, where X represents the number of prior consecutive pecks on the left or right key. This type of analysis was performed under a variety of initial-link conditions to be described in those sections dealing with Experiments 2, 3, and 4.

GENERAL METHOD

Subjects

Eleven male White Carneaux pigeons were maintained at 80% of free-feeding weight. All of the birds had previously responded under concurrent chained schedules.

Apparatus

The experimental chamber contained two translucent response keys located 7.6 cm apart and 9.5 cm above the floor. Tricolor projectors (BRS/LVE #111-05) were used to transilluminate the keys with red, green, or white light. Each peck on a lighted key that exceeded a force of .118 *N* produced a feedback click by operating a 24-V DC relay behind the panel. A solenoid-operated grain hopper which provided access to mixed grain was centrally located between the keys. During reinforcement, which lasted 3 sec, the feeding aperture was lit, and the keylights and 24-V DC houselight were turned off. A ventilation fan attached to the sound-attenuating shell containing the chamber masked extraneous sounds. Solid state equipment (BRS/LVE DigiBits) programmed experimental conditions, and electromechanical counters and timers recorded events. The apparatus described above was used in Experiments 1, 3, and 4. Experiment 2, which was performed at the University of California, San Diego, employed similar apparatus except electromechanical rather than solid state equipment programmed conditions and a speaker located inside the sound-attenuating shell masked extraneous sounds with white noise. Also, during reinforcement, which lasted 3.25 sec, the key last pecked remained lit.

Procedure

All of the experiments comprising the present study employed concurrent chained schedules. Those features of the procedure common to the four experiments are described below; additional details of the procedure will be discussed as they became relevant.

A diagram of the concurrent-chains procedure appears in Figure 1. Two equal variable-interval (VI) 1-min schedules independently arranged access to the terminal links. When the terminal link on one side became available, the VI timer associated with that terminal link stopped operating. The other timer continued to operate if the interval which it was timing had not yet elapsed. Whenever a peck produced a terminal link, the color of the key changed and the other key became dark and inoperative. Further responding on the lighted key produced food on one of three schedules: FI, fixed ratio (FR), or variable ratio (VR). Neither VI timer operated while a

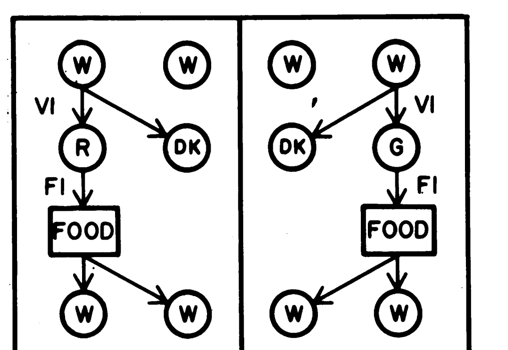

Fig. 1. Diagram of the concurrent-chains procedure. The panels on the left and right sides of the diagram illustrate the sequence of events when pecks on the left and right keys, respectively, produced reinforcement.

terminal link was in progress. On return to the initial links, both VI timers started again except in the following case: if both terminal links had been available at the time one of the terminal links was entered, the terminal link not entered remained available upon return to the initial links.

Experimental conditions involved manipulations of the initial or terminal links, and they remained in effect until the daily choice proportions satisfied a stability criterion (Experiments 1 and 2) or until 20 sessions had been administered (Experiments 3 and 4). The data indicated that 20 sessions were sufficient for obtaining stable sequential patterning. The procedure for assessing the stability of choice proportions was as follows. Following the 18th session and every session thereafter until stability was reached, the choice proportions of the last nine sessions were divided into three successive blocks of three sessions each. Stability was considered to be present when two conditions were met: (a) there was neither an upward nor a downward trend in the means of the blocks, that is, neither $M_1 < M_2 < M_3$, nor $M_1 > M_2 > M_3$; and (b) no block mean differed from any other by more than .05.

EXPERIMENT 1: SEQUENTIAL DEPENDENCIES WITHOUT A CHANGEOVER DELAY

Subjects

The experiment employed four subjects.

Procedure

Each bird performed in seven experimental conditions with VI 1-min schedules in the initial links. In the first condition, both the left and right terminal links consisted of FI 10-sec schedules. The schedule on one side was designated the "Standard" schedule and was held constant throughout the next five conditions. The FI schedule on the other side, the "Comparison" schedule, varied in duration; over Conditions 2 through 5, its values were 5, 15, 20, and 25 sec. The order of presentation was different for each subject, with two birds (Bird 1405 and Bird 950) receiving the Comparison schedule in the left terminal link, and two birds (Bird 83 and Bird 1420) receiving the Comparison schedule in the right terminal link. The sixth condition was a replication of one of the previous five conditions. It was selected at random with the constraint that it did not duplicate the condition replicated for any other subject. The duration of the Comparison schedule in the replication condition was 20 sec for Bird 1405, 15 sec for Bird 1420, 10 sec for Bird 83, and 5 sec for Bird 950. In the last condition, both terminal links consisted of FI 25-sec schedules.

Analysis of temporal patterning. Blough (1966) noted that the frequencies with which organisms emit interresponse times (IRTs) on intermittent schedules are seldom randomly distributed. Some IRTs are emitted with a higher probability than other IRTs, and this lack of randomness is a sign of functional interdependence between pecks. In the present experiment, to calculate the value $P_{L|R}$ and $P_{L|L}$, it was necessary to record the frequency with which the organism emitted the sequences, R-L, R-R, L-R, and L-L. These frequencies were further sorted into six IRT categories, the ranges of which were: 51 to 250 msec, 251 to 450 msec, 451 to 650 msec, 651 to 850 msec, 851 to 1050 msec, and 1051+ msec. The counters did not register pecks which occurred with IRTs of 50 msec or less. To reveal more clearly whether the emission of IRTs was random, the frequency distribution for each type of sequence was converted to a distribution of "interresponse times per opportunity," or IRTs/Op (Anger, 1956). An IRTs/Op function expresses the conditional probability that a peck will occur with an IRT in a particular range, rather than with a longer IRT, given that sufficient time has elapsed to permit a peck in that range. Changes in the conditional probability of a peck as a function of time such as an upward or downward trend, or a modal value in a particular category, would reflect functional interdependence between pecks (Blough, 1966). In Experiment 1, distributions of IRTs/Op were obtained separately for each type of sequence and for each pair of terminal-link schedules listed in the previous paragraph.

Termination of experimental conditions. Experimental conditions remained in effect for three sessions beyond the point at which the choice proportions satisfied the stability criterion. Values reported in this experiment were obtained by summing raw data across the last three sessions and dividing by three. Before the last three sessions, the apparatus recorded no sequential data. Instead, two 12-

category IRT distributions were obtained—one in which the peck terminating the IRT was on the left key, and one in which the terminal peck was on the right key. The apparatus did not permit further sorting of the data according to the location of the peck initiating the IRT. These data were relatively uninformative and will not be reported.

An exception to the foregoing rules for terminating experimental conditions was the setting of a 40-session limit for attaining stability There were two cases in which the 40-session limit applied. In one case (Bird 1420, FI 10-sec vs. FI 20-sec), 3 additional sessions beyond the 40 were conducted to obtain sequential data and IRT data. In the other case (Bird 1405, FI 25-sec vs. FI 25-sec), sequential and IRT data were obtained in each of the 40 sessions, and extension of experimental conditions was unnecessary; the data were averaged over sessions 38-40.

Results and Discussion

Table 2 presents the mean dependency index values for each subject as a function of the duration of the Comparison schedule. The table also shows the high and low values of the dependency index for the three sessions on which the averages are based. Positive values of the index represent switching dependencies; negative values represent repetition dependencies. Large switching dependencies appeared in the performances of two subjects, Birds 1405 and 950. The other two subjects (Birds 1420 and 83) exhibited much smaller switching dependencies. In all cases, the magnitude of switching dependencies was greatest when the Standard and Comparison schedules were equal or similar in duration (Comparison schedules FI 5-sec, FI 10-sec, and FI 15-sec). A Friedman 2-way analysis of variance by ranks indicated that the mean dependency index values decreased significantly as the duration of the Comparison schedules increased ($\chi_r^2 = 12.40$, $N = 4$, $k = 4$, $p < .02$). That the magnitude of switching dependencies varied both with subjects and terminal-link values suggests that one may have to decide for each subject and each pair of terminal-link schedules whether a changeover delay should be used.

With FI 25-sec in both terminal links, switching dependencies were in most cases substantial. For Bird 1405, the mean dependency index value was .36 (range .40 to .33), for Bird 950, .26 (range .31 to .25), and for Bird 1420, .13 (range .16 to .12). Bird 83, which developed a large key bias in this condition (choice proportion on left key = .81), exhibited a negligible dependency (mean = −.07, range .03 to .10). Thus, strong switching dependencies may appear in concurrent chained schedules even when a relatively long delay separates initial-link responding from food reinforcement.

Table 3 presents the rates at which subjects emitted the sequences used to calculate the conditional probabilities: successive pecks on the Standard key (S-S), successive pecks on the Comparison key (C-C), and changeovers (CO)

Table 2

Mean Dependency Index Values and Ranges, Experiment 1

		*Comparison schedules (FI x-sec)**					
Bird	*Statistic*	*5*	*10*	*15*	*20*	*25*	*Replication*
1405	Average	.42	.46	.44	.11	.14	.25 (FI 20-sec)
	High	.44	.52	.47	.17	.19	.32
	Low	.40	.38	.40	.03	.11	.21
950	Average	.46	.26	.24	.03	.11	.29 (FI 5-sec)
	High	.51	.32	.34	.35	.17	.31
	Low	.42	.24	.15	−.41	.08	.26
83	Average	.09	.13	.13	−.12	.01	.21 (FI 10-sec)
	High	.14	.16	.20	−.01	.08	.23
	Low	.01	.11	.07	−.17	−.12	.18
1420	Average	.13	.15	−.01	−.04	−.06	.07 (FI 15-sec)
	High	.17	.24	.05	.09	.04	.15
	Low	.09	.15	−.04	−.11	−.19	−.01

*Standard schedule was FI 10-sec.

from one key to the other (S-C and C-S combined). The table also gives the overall choice proportion for the Comparison schedules and the total number of sessions conducted under each condition. For ease of inspecting the table, the Comparison schedules are arranged in order from FI 5-sec to FI 25-sec, although one should keep in mind that during the experiment the birds received the Comparison schedules in different orders. Choice proportions varied considerably within subjects when terminal-link schedules were equal (FI 10-sec vs. FI 10-sec, FI 25-sec vs. FI 25-sec). This variability may seem puzzling in light of the fact that switching dependencies were strongest with equal terminal links, thus increasing the tendency toward equal responding on the two keys. To a large extent, order effects seem to have contributed to the difference between choice proportions under the two sets of terminal-link conditions. For each subject, these choice proportions were more similar to those in the immediately preceding conditions than they were to each other. For example, for Bird 1405, the two choice proportions under equal terminal-link conditions were .50 and .31 (difference = .19), while the values in the immediately preceding conditions were .44 and .28, respectively (differences = .06 and .03). Such order effects apparently offset any equalizing tendency created by the switching dependencies under equal terminal links.

It is noteworthy that the overall rates of initial-link responding remained roughly constant across Comparison schedules whereas the rates at which subjects emitted changeovers and successive pecks on a key changed dramatically. Friedman 2-way analyses of variance

Table 3

Rate of emission of changeovers (C.O.) and successive pecks on the standard (S-S) and comparison (C-C) keys (sequences/min).

Bird	*Comparison schedule (FI x-sec)*[a]	*Choice proportion (comparison)*	*Initial-link response rate*	*Sequence*			*Sessions*
				S-S	*C.O.*[b]	*C-C*	
1405	5	.44	75.63	16.07	52.75	6.81	42
	10	.50	48.78	6.32	35.65	6.81	21
	15	.41	55.56	13.93	38.43	3.20	29
	20	.30	51.72	24.64	22.98	4.10	22
	25	.29	54.39	25.89	25.48	3.02	24
	20Rep.	.28	55.46	25.82	28.09	1.54	22
	25-25	.31	44.00	17.63	25.58	0.79	40[c]
950	5	.55	51.10	4.87	36.99	9.24	21
	10	.66	38.63	2.01	21.61	15.02	21
	15	.46	50.33	11.84	30.91	7.59	21
	20	.33	52.34	22.97	23.85	5.52	25
	25	.11	54.30	41.70	12.51	0.09	26
	5Rep.	.51	63.94	10.03	42.12	11.79	31
	25-25	.47	49.16	9.53	30.79	8.84	19
1420	5	.30	29.35	13.75	13.91	1.68	24
	10	.38	29.45	10.13	16.08	3.24	21
	15	.18	28.69	19.19	8.47	1.03	25
	20	.26	22.35	12.49	8.20	1.63	43[c]
	25	.05	21.47	19.54	1.84	0.10	25
	15Rep.	.48	27.50	7.21	14.72	5.57	23
	25-25	.52	24.80	4.61	14.01	6.18	21
83	5	.69	29.79	2.36	13.94	13.48	23
	10	.43	31.50	9.38	17.07	5.06	21
	15	.27	32.05	16.10	14.43	1.51	27
	20	.15	33.99	24.87	7.78	1.34	22
	25	.18	32.71	22.00	9.76	0.94	28
	10Rep.	.40	31.63	9.95	18.34	3.33	27
	25-25	.19	20.94	13.84	6.10	1.00	21

[a]Standard schedule was FI 10 sec in all but last condition, in which it was FI 25 sec.
[b]Both directions combined.
[c]40 day limit reached.

by ranks were performed on initial determinations of these values under the FI 10-sec Standard schedule and the Comparison schedules, FI 10-, 15-, 20-, and 25-sec ($N = 4$, $k = 4$). Data obtained under the FI 5-sec Comparison schedule were excluded because trends present under the other Comparison schedules often reversed on this side of the equality point (FI 10-sec vs. FI 10-sec). The analysis of variance indicated a significant decrease in the frequency of C-C sequences as the duration of the Comparison schedules increased ($\chi_r^2 = 10.80$, $p = .0016$), a significant decrease in the frequency of changeovers ($\chi_r^2 = 7.50$, $p = .052$), and a significant increase in the frequency of S-S sequences ($\chi_r^2 = 9.90$, $p = .0062$). The overall rate of initial-link responding did not change significantly ($\chi_r^2 = 1.80$, $p = .677$). Thus, the increase in frequency of successive pecks on the Standard key approximately balanced the decrease in changeovers and successive pecks on the Comparison key. These correlations suggest a kind of interdependence among pecks whereby a change in the frequency of one class of pecks may necessitate a commensurate change in the frequency of other classes.

Temporal Patterns of Responding

Switching dependencies may arise in concurrent chained schedules in much the same way as they are thought to arise in simple concurrent schedules. Occasionally, a peck that produces a terminal link directly follows a peck on the other key. With a sufficiently short delay between pecks, the first peck in the sequence may come to act as a discriminative stimulus for a peck on the other key. A possible by-product of this process is the acquisition of a short IRT as part of the superstition. A distribution of IRTs/Op would reveal such a temporal pattern as a mode, or peak, in a class interval of relatively short IRTs. Peaks were in fact present in the IRTs/Op functions of all subjects, but most markedly and consistently in the functions of those subjects which showed the strongest switching dependencies in Table 2—Birds 950 and 1405.

Figures 2 and 3 present the IRTs/Op functions for Birds 950 and 1405, respectively. Going from the panels at the top of the figures to the panels at the bottom, the Comparison schedules presented for choice with the Standard are increasing in duration. Panels

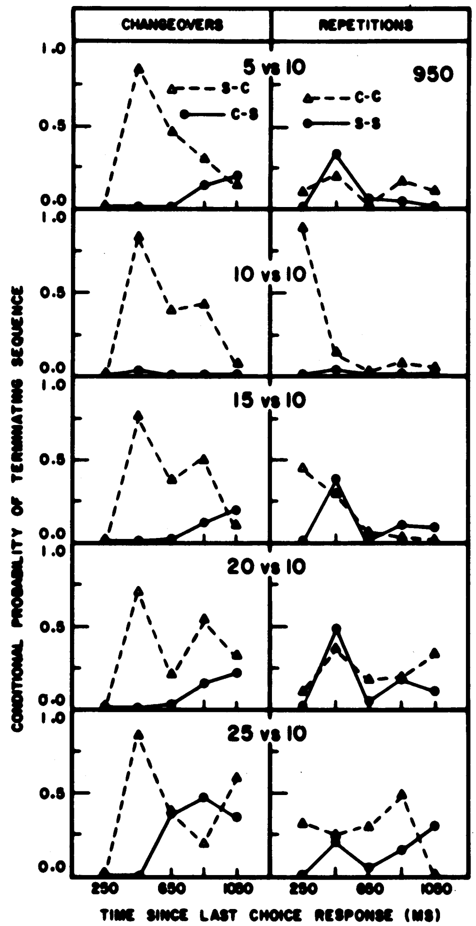

Fig. 2. Distributions of interresponse times per opportunity (IRTs/Op) for one subject (Bird 950) in Experiment 1. The figure illustrates the temporal patterns that characterized emission of four basic sequences: changeovers from the Standard key to the Comparison key (S-C), changeovers from the Comparison key to the Standard (C-S), successive pecks on the Comparison key (C-C), and successive pecks on the Standard key (S-S). Each function represents the conditional probability that the terminal peck in a sequence would fall in one of five IRT categories, given that sufficient time had elapsed since the peck initiating the sequence to make a peck in that category possible. The numbers along the abscissa are the upper limits of the IRT categories, each of which had a 200-msec range. Going from the panels at the top of the figure to the panels at the bottom, the duration of the Comparison schedules are increasing, as indicated by the numbers that cross the midline of each pair of panels. A horizontal distribution of IRTs/Op represents a random pattern of emission. Deviations from a horizontal distribution, such as a peak in a particular IRT category, signify functional interdependence between pecks.

on the left side of the figures show the IRTs/Op functions for the changeover sequences, C-S (dots) and S-C (triangles). Panels on the right side show the IRTs/Op functions for the repetition sequences, S-S (dots) and C-C (triangles). Sharp peaks characterized the emission of both changeovers and repetitions. Changeovers from Standard to Comparison were most likely to occur with short IRTs: 251 to 450 msec for Bird 950 and 451 to 650 msec for Bird 1405. Changeovers from Comparison to Standard generally occurred with longer IRTs but the IRTs decreased as the size of the Comparison schedules increased. In both subjects, the repetition sequence, S-S, also displayed consistent peaks, the peaks falling in the class interval, 251 to 450 msec. Thus, during the initial links of concurrent chained schedules, subjects often emit sequences with IRTs within a restricted range. This temporal stereotypy is consistent with the view that sequential dependencies arise through a process of superstitious chaining. However, until data are available that explicitly trace the development of sequential dependencies, any view of how dependencies originate must remain tentative.

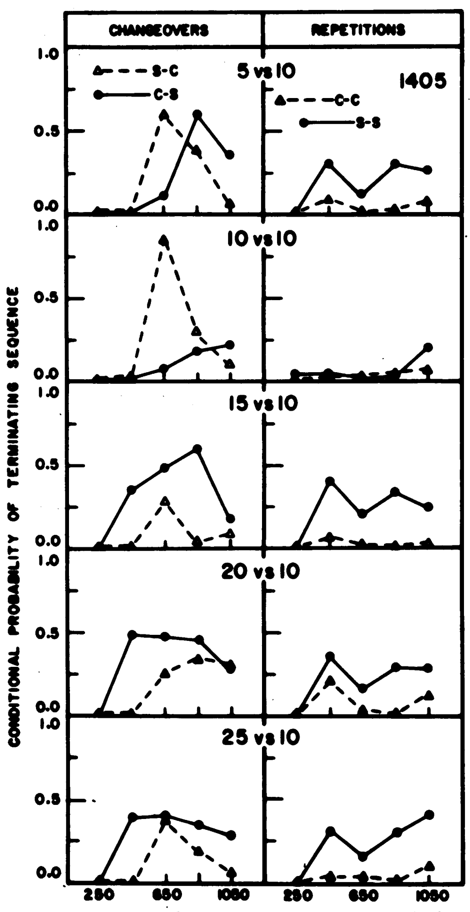

Fig. 3. Distributions of IRTs/Op for Bird 1405, Experiment 1. The format of the figure is identical to that of Figure 2.

EXPERIMENT 2: SEQUENTIAL PATTERNING UNDER A CHANGEOVER DELAY

It is customary in simple concurrent schedules to employ a changeover delay to minimize superstitious switching. Although the changeover delay reduces the frequency of switching, it typically produces another sequential pattern: a changeover to a key initiates a rapid series of pecks on the key that continues at least for the duration of the changeover delay interval (Catania, 1966; Silberberg & Fantino, 1970). The objective of Experiment 2 was to ascertain whether the changeover delay produces a similar sequential pattern in concurrent chained schedules. In the context of the present analysis, bursts of successive pecks on a key should appear as a "repetition dependency"—the probability of a peck on the left key should be higher if the last peck was on the left than if the last peck was on the right. The analysis was at a more molecular level than that in Experiment 1, focusing on choice as a function of the exact number of consecutive pecks on the left or right key.

Method

Subjects

The experiment employed four subjects. All had previously responded under concurrent chained schedules.

Procedure

Conditional probabilities. The analyses performed in this and the subsequent experiments were in terms of the conditional probabilities, $P_{L|XL}$ and $P_{L|XR}$, where X represents the number of consecutive pecks on the left or right key. The raw data from which these values were calculated were frequency distributions of run lengths (Mechner, 1958; Navarick, 1973; Silberberg & Williams, 1974). One or more pecks on a key before a changeover to the other key constituted a run. The length of a run was the number of consecutive pecks prior to the changeover. From the frequency distribution of run lengths, conditional probabilities were calculated by a procedure similar to that used to calculate IRTs/Op. The conditional probabilities expressed the probability that a run of length n would be terminated given that exactly n consecutive pecks had occurred. To illustrate, suppose that a subject emitted on the right key runs of length 1 to 6 or greater with the following frequencies: 800, 140, 36, 12, 6, 6. The probability of terminating a run of length 1 given exactly 1 peck on the right key would be $800/1000 = .80$. The probability of terminating a run of length 2 given exactly 2 consecutive pecks on the right key would be $140/200 = .70$. The conditional probabilities of terminating runs of length 3 to 5 would be .60, .50, and .50, respectively. These values would represent the conditional probabilities, $P_{L|XR}$. The conditional probabilities, $P_{L|XL}$ (the probability of *not* terminating a run on the left key), were calculated in the same way except that the obtained values were subtracted from 1.00. In Experiment 2, the apparatus recorded separately runs of length 1 to 9, and included in a single category runs of length 10 or more.

Experimental conditions. The pigeons responded under three experimental conditions in an ABA design. Two birds (2939 and 3932) started the experiment with no changeover delay in the initial links, then, in the second condition, performed with a changeover delay of .5 sec, and lastly responded again without a changeover delay. The other two subjects (Birds 3427 and 4189) started with COD .5-sec, then performed without a changeover delay, and lastly responded again with COD .5-sec. A changeover delay interval of .5 sec was selected so that many values of X in $P_{L|XL}$ and $P_{L|XR}$ would lie outside the changeover delay interval. It seemed reasonable to assume that the changeover delay interval would usually elapse before runs exceeding three pecks occured. Choice probabilities following extended runs might therefore be expected to reflect attenuation of the burst pattern that normally occurs during the changeover delay interval: as X increases, $P_{L|XL}$ may decrease while $P_{L|XR}$ may increase.

It seemed desirable to hold constant the overall choice proportions across the three conditions, inasmuch as changes in the choice proportions might alone have influenced sequential patterns of responding. Under simple concurrent schedules, changeover delays typically increase the overall proportion of responses on the schedule providing the higher rate of reinforcement (e.g., Herrnstein, 1961). To increase the likelihood that choice proportions would be comparable with and without a changeover delay, the schedules presented in the terminal links were those expected to produce approximate indifference. For three birds (3427, 2939, and 4189), both terminal links consisted of FR 15 schedules. The change from FI schedules in Experiment 1 to FR schedules in Experiment 2 would provide some indication of the generality of phenomena previously described. The fourth bird (3932) had recently completed an experiment in which it had exhibited indifference between FI 17.3-sec (left key) and VR 90 (right key); these schedules were used in the present experiment.

Conditions were terminated after the choice proportions satisfied the stability criterion described in the General Method. Data were averaged over the last three sessions of a condition. For each subject, the total number of sessions for conditions I, II and III, respectively, was as follows: Bird 3932—18, 22, 18; Bird 4189—26, 18, 20; Bird 2939—25, 20, 18; Bird 3427—21, 23, 19.

Results and Discussion

Figure 4 presents for each subject the conditional probability of a peck on the left key given X consecutive pecks on the left (dots) and X consecutive pecks on the right (triangles). The decimal values in the panels are the choice proportions on the left key. If there were no sequential dependencies in initial-link responding, no consistent differences would exist between the functions, $P_{L|XL}$ and $P_{L|XR}$, and the functions would be approximately horizontal, intersecting the ordinate at a value equal to the choice proportion.

The .5-sec COD produced strong repetition dependencies in all subjects, with $P_{L|XL}$ exceeding $P_{L|XR}$ at all values of X. As the number of consecutive pecks on a key increased, the differences between $P_{L|XL}$ and $P_{L|XR}$ decreased, indicating attenuation of the dependencies after the changeover delay intervals elapsed. In the absence of a changeover delay,

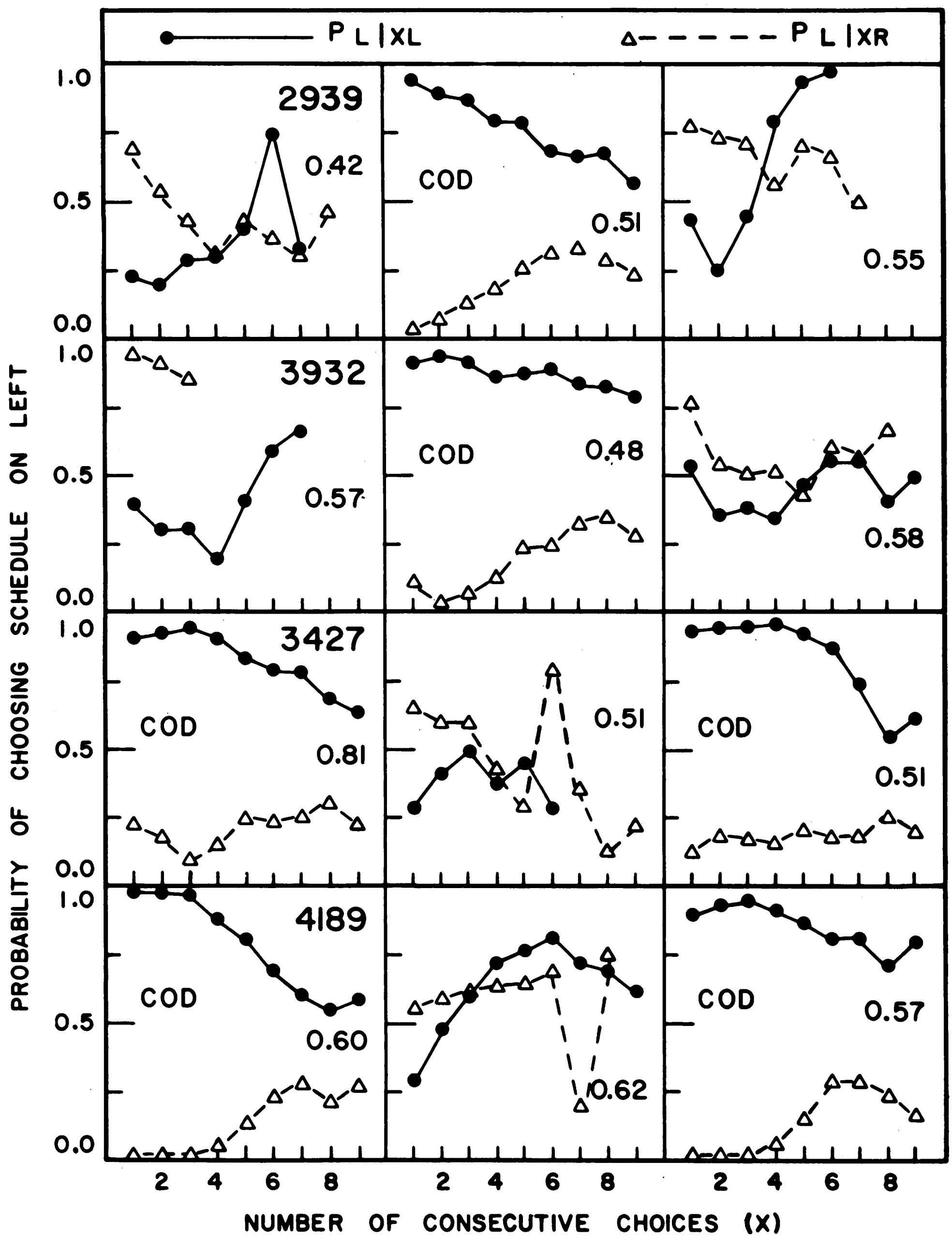

Fig. 4. The conditional probabilities of a peck on the left key given X consecutive pecks on the left ($P_{L|XL}$) or X consecutive pecks on the right ($P_{L|XR}$), Experiment 2. The duration of the changeover delay was .5 sec. Terminal-link schedules were so arranged as to produce choice proportions of approximately .50. If there were no sequential dependencies, no consistent differences would exist between the two functions and they would be approximately horizontal, intersecting the ordinate at a value equal to the choice proportion shown in the panel.

all subjects exhibited switching dependencies. The dependencies were strongest when precisely one or relatively few consecutive pecks on a key preceded a choice, suggesting that there may have been some tendency for changeovers to occur in succession (e.g., left-right-left). At higher values of X, performances became more variable both within and between subjects. For example, Bird 2939 exhibited a repetition dependency in the replication of the no-changeover delay condition that was not present in the initial determination. Bird 4189 exhibited a repetition dependency, but Birds 3932 and 3427 did not. The greater variability in the relationship between $P_{L|XL}$ and $P_{L|XR}$ at higher values of X may have resulted from the smaller number of runs available to calculate the functions at these values. Due to the strong tendency to switch after relatively few consecutive pecks on a key, there were fewer long runs than short runs. In general, the results indicate that the introduction of a .5-sec COD eliminates switching dependencies in initial-link responding but replaces them with strong repetition dependencies.

EXPERIMENT 3: SEQUENTIAL DEPENDENCIES UNDER RESPONSE-DEPENDENT BLACKOUTS

Experiment 1 showed that in the absence of a changeover delay, initial-link performances often exhibited switching dependencies. Introduction of a .5-sec COD in Experiment 2 eliminated switching dependencies but produced large repetition dependencies. In Experiment 3, a variation of the changeover delay that might expected to produce greater independence among pecks was studied. Each changeover to a key initiated a blackout in the chamber lasting the duration of the changeover delay interval (Silberberg & Fantino, 1970; Todorov, 1971). Because pigeons rarely respond in a dark chamber, presentation of a blackout dependent on changeovers eliminates the burst of responding that ordinarily occurs during the changeover delay interval (Silberberg & Fantino, 1970). The present experiment directly compared the effects of the changeover delay and blackout procedures by studying the performances of the same pigeons under both conditions.

METHOD

Subjects

Five pigeons served as subjects. All had previously responded under concurrent chained schedules without a changeover delay or blackout. Bird 1405 was a subject in Experiment 1.

Procedure

Throughout the experiment, the terminal links consisted of FI 5-sec schedules. In the first condition, the pigeons responded under the regular concurrent chains procedure which included neither a changeover delay nor a blackout dependent on changeovers. Two subjects (Birds 7697 and 7598) responded with a 2-sec COD in the second condition; Birds, 1411, 859, and 1405 performed with a 2-sec blackout. The blackout procedure was identical to the changeover delay except for two features: (a) the houselight and keylights were turned off during the 2-sec interval following a changeover, and (b) keypecks during the blackout produced no feedback clicks. Silberberg and Fantino (1970), using simple concurrent schedules, reported that responding was eliminated during blackouts of .875-sec and 3.5-sec duration. Informal observation in the present experiment indicated that responding was negligible during the 2-sec blackouts. The third experimental condition was a replication of the first in which there was neither a changeover delay nor a blackout The fourth condition instituted a 2-sec COD for those subjects which had received a blackout in the second condition, and a 2-sec blackout for those subjects which had received a changeover delay. The values, $P_{L|XL}$ and $P_{L|XR}$, were recorded in all of the conditions, and included pecks that occurred both during and after the 2-sec intervals. Conditions were terminated after 20 sessions. Raw data were summed over the last five sessions and divided by 5.

RESULTS AND DISCUSSION

The main purpose of this experiment was to determine whether a blackout dependent on switching maintained greater independence among pecks than a changeover delay of equal duration. For the purpose of comparing the overall effects of these procedures, Table 4 presents for each subject the conditional probabilities, $P_{L|L}$ and $P_{L|R}$, and the mean dependency index values, under the blackout, changeover delay, and regular concurrent-chains procedure. As an indication of within-subjects variability, Table 4 also gives the highest and the lowest values of the dependency index during the five-session period on which the means are based. Before the intro-

Table 4

Conditional probabilities of a peck on the left key in the four experimental conditions of experiment 3, given that the last peck was on the left ($P_L|_L$) or on the right ($P_L|_R$).

Bird	Condition	Choice proportion (L)	$P_L\|_R$	$P_L\|_L$	Dependency Index[a] ($P_{L\|R}$-$P_{L\|L}$) Mean	High	Low	Change from baseline
1411	Regular	.49	.70	.26	.44	.48	.43	
	Blackout 2-sec	.45	.35	.58	−.23	.10	−.35	−.67
	Regular	.48	.57	.38	.19	.47	−.03	
	COD 2-sec	.67	.28	.85	−.57	−.47	−.59	−.76
7697	Regular	.32	.36	.22	.14	.24	−.32	
	COD 2-sec	.51	.14	.86	−.72	−.67	−.74	−.86
	Regular	.56	.52	.58	−.06	.08	−.25	
	Blackout 2-sec	.50	.24	.76	−.52	−.40	−.61	−.46
7598	Regular	.48	.61	.34	.27	.32	.24	
	COD 2-sec	.47	.14	.84	−.70	−.70	−.72	−.97
	Regular	.40	.40	.40	.00	.04	−.03	
	Blackout 2-sec	.60	.33	.88	−.47	−.42	−.48	−.47
859	Regular	.48	.78	.15	.63	.70	.55	
	Blackout 2-sec	.52	.47	.56	−.09	.00	−.20	−.72
	Regular	.55	.76	.38	.38	.46	.34	
	COD 2-sec	.44	.42	.48	−.06	.03	−.08	−.44
1405	Regular	.43	.59	.23	.36	.39	.28	
	Blackout 2-sec	.44	.26	.66	−.40	−.28	−.54	−.76
	Regular	.46	.61	.29	.32	.38	.23	
	COD 2-sec	.58	.17	.88	−.71	−.65	−.78	−1.03

[a]Positive values represent switching dependencies; negative values represent repetition dependencies.

duction of the changeover delay and blackout (first condition), all of the subjects exhibited strong switching dependencies. For the five pigeons, the dependency index averaged .37 with a range in the means of .14 to .63. Introduction of the changeover delay or blackout in the second condition produced substantial repetition dependencies in most cases (dependency index average, −.43; range, −.72 to −.09), while removal of these procedures in the third condition consistently resulted in an increase in switching (dependency index average, .17; range, −.06 to .38). In the fourth condition, presentation of a changeover delay for those subjects that had previously responded with a blackout and presentation of a blackout for those subjects that had previously responded with a changeover delay, consistently produced repetition dependencies (dependency index average, −.47; range, −.06 to −.71).

In comparing the effects of the changeover delay and the blackout, it is necessary to take into account the decline in switching that occurred from the first condition (.37) to the third (.17). One approach is to measure the change from the immediately preceding value of the dependency index brought about by introduction of the changeover delay or blackout. The magnitude of this change may be calculated by subtracting the value of the dependency index in the baseline condition from the value of the index in the next changeover delay or blackout condition. The procedure that brought about the greater change in the dependency index would be the one that induced the stronger repetition dependency. The changes from baseline appear in the last column of Table 4. In all but one case (Bird 859), the changeover delay induced a substantially stronger overall repetition dependency than the blackout. Thus, while both the 2-sec COD and the 2-sec blackout produced repetition dependencies, the blackout tended to maintain greater independence among pecks.

Sequential Patterning

Figure 5 illustrates the results at a more molecular level of analysis, depicting for each subject the values, $P_{L|XL}$ and $P_{L|XR}$, under the four experimental conditions. Each row of panels presents the results for one subject.

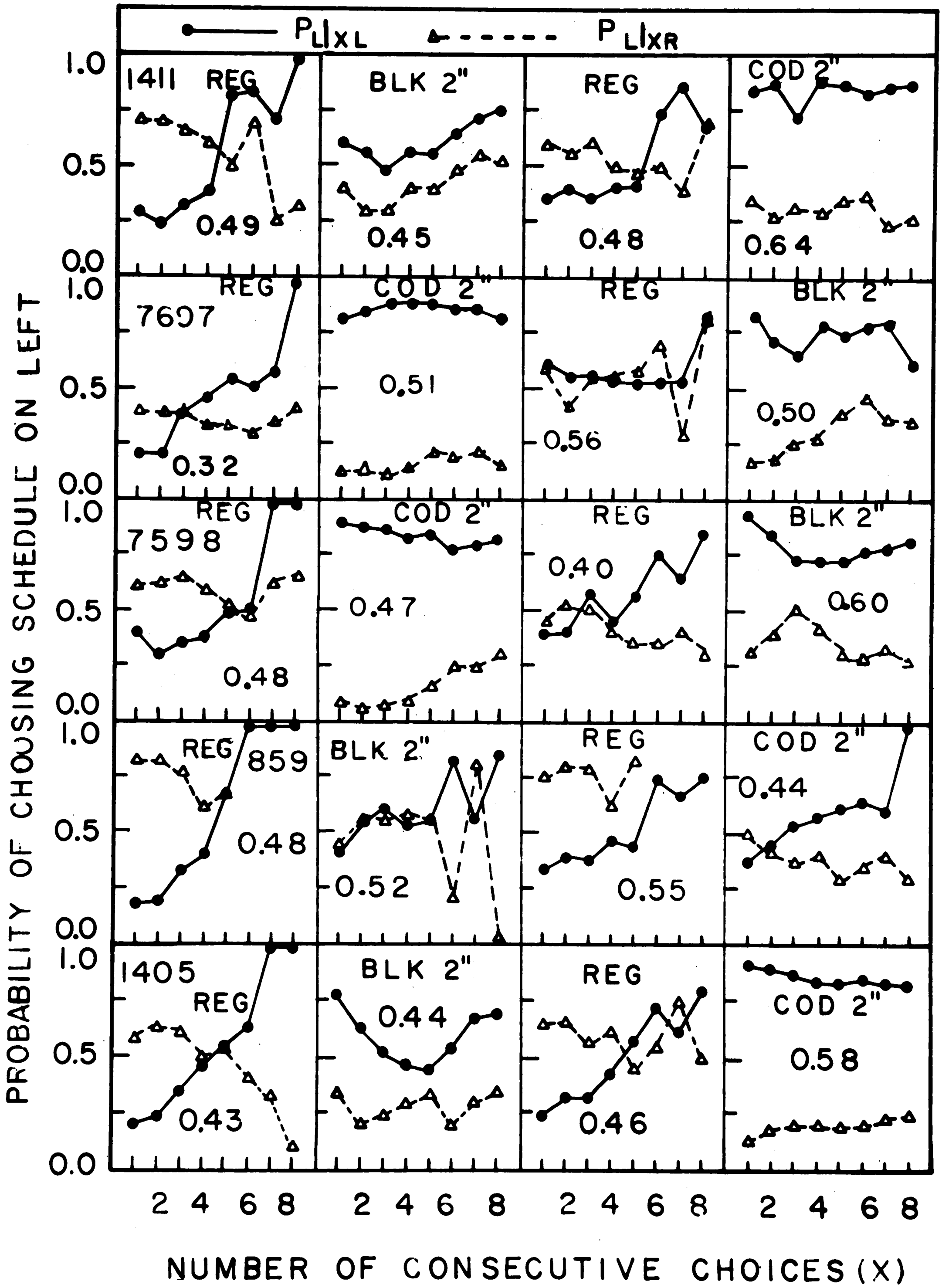

Fig. 5. The values, $P_{L|XL}$ and $P_{L|XR}$, under the regular concurrent-chains procedure, a 2-sec COD, and a 2-sec blackout contingent upon switching. All initial-link pecks, including those during the 2-sec interval, contributed to the values, although pecks during the blackout were rare. Throughout the experiment, both terminal links consisted of FI 5-sec schedules.

In the first condition (leftmost column of panels), the magnitude of the switching dependencies decreased in all subjects as the number of consecutive pecks on a key increased. This reduction in switching was similar to that found in Experiment 2 (Figure 4). A Friedman 2-way analysis of variants by ranks indicated that the differences, $P_{L|XR} - P_{L|XL}$, decreased significantly across the first five consecutive pecks ($\chi_r^2 = 17.80$, $N = 5$, $k = 5$, $p < .01$). Viewing the present results together with those of Experiments 1 and 2, it may be concluded that switching dependencies in concurrent chains are strongest when the terminal links are identical or similar in duration (Experiment 1) and when precisely one or relatively few consecutive pecks on a key precede the choice (Experiments 2 and 3).

Neither subject (Birds 7697 and 7598) that had responded with the 2-sec COD in the second condition exhibited a substantial switching dependency when the changeover delay was removed in the third condition. However, strong switching dependencies did reappear in the performances of the three birds that had previously responded with the blackout (Birds 1411, 859, 1405). As in the first condition, the differences, $P_{L|XR} - P_{L|XL}$, decreased significantly across the first five consecutive pecks on a key ($\chi_r^2 = 9.93$, $N = 3$, $k = 5$, $p < .05$).

Sequential patterns of responding under the changeover delay and blackout were similar. With only one exception (Bird 859, blackout procedure), the values $P_{L|XL}$ consistently exceeded the values $P_{L|XR}$; that is, the repetition dependency was maintained at least across the first eight consecutive pecks on a key. It was mainly in the overall magnitude of the repetition dependencies (Table 4) that the blackout and changeover delay were distinguishable. In general, the present data, together with those of Experiment 2, indicate that sequential patterning under a changeover delay and blackout differ fundamentally from those under the regular concurrent-chains procedure.

EXPERIMENT 4: SEQUENTIAL DEPENDENCIES UNDER CHANGEOVER DELAY AND BLACKOUT PROCEDURES WITH UNEQUAL TERMINAL LINKS

In Experiments 2 and 3, the terminal links were so arranged as to produce choice proportions of approximately .50 in the initial links. The purpose was to increase the likelihood that choice proportions would remain roughly constant across experimental conditions, as changes in the choice proportions might alone have influenced sequential patterning. Experiment 4 tested the generality of conclusions from the previous experiments under conditions in which the choice proportions deviated substantially from .50. The experimental design was similar to that of Experiment 3 except that the FI schedules in the terminal links differed in duration.

METHOD

Subjects

The experiment employed the same five pigeons that served in Experiment 3.

Procedure

Throughout the experiment, one terminal-link schedule was FI 5-sec and the other was FI 15-sec. The FI 5-sec schedule was on the left side for Birds 859 and 7697, and on the right side for Birds 1405, 7598, and 1411. In the first experimental condition, all of the subjects responded under the regular concurrent-chains procedure (no changeover delay or blackout). The three pigeons that had performed under a 2-sec blackout in the second condition of Experiment 3 (Birds 1411, 859, and 1405) received a 2-sec COD in the second condition of the present experiment. The other two subjects (Birds 7697 and 7598) received a 2-sec blackout in the second condition. The third condition was a replication of the first, and the fourth condition instituted a changeover delay or a blackout, whichever procedure the subject had not been administered in the second condition. As in Experiment 3, conditions were terminated after 20 sessions. Raw data were summed over the last five sessions and divided by 5.

RESULTS AND DISCUSSION

In Experiment 3, with equal terminal links, the changeover delay tended to generate stronger repetition dependencies than the blackout. In the present experiment, with unequal terminal links, the changeover delay continued to maintain stronger repetition dependencies. The overall effects of these procedures can be seen in Table 5, which is analogous in all respects to Table 4 in the last experiment. Choice proportions for the FI schedule of shorter duration tended to be higher under the changeover delay (mean = .84; range, .72 to .96) and the blackout (mean = .84; range = .67 to .96) than under the regular concurrent-chains procedure (mean = .72; range = .56 to .82). In four of the five subjects, the changeover delay produced a greater change in the negative direction from the baseline value of the dependency index than did the blackout. The subject for which the blackout produced the greater negative change (Bird 859) was also the subject for which the blackout produced the greater negative change in Experiment 3. The results of Experiments 3 and 4 indicate that sequential dependencies in initial-link responding are strongly influenced by stimulus conditions prevailing during the delay period initiated by changeovers. In most cases, filling the delay with a blackout attenuates the strong repetition dependencies generated by a conventional changeover delay.

Sequential patterns of responding appear in Figure 6, which presents two conditional probability functions for each subject: (a) the probability of a peck for the FI schedule of shorter duration as a function of the number of consecutive pecks for the FI schedule of longer duration ($P_{S|XL}$), and (b) the probability of a peck for the FI schedule of shorter duration as a function of the number of consecutive pecks for that schedule ($P_{S|XS}$). Under the regular concurrent-chains procedure (first and third columns), sequential patterns of responding resembled those found in Experiment 3 with equal terminal links: the tendency to switch was strongest when relatively few consecutive pecks on a key preceded the choice. Friedman 2-way analyses of variance by ranks indicated that the differences, $P_{S|XL} - P_{S|XS}$, decreased significantly across the first five consecutive pecks on a key (first condition: $\chi_r^2 = 12.20$, $N = 5$, $k = 5$, $p < .02$; third condition: $\chi_r^2 = 14.72$, $p < .01$). The blackout procedure generated a pattern not found with unequal terminal links: $P_{S|XL}$ increased then decreased as a function of X. This pattern did not appear under the changeover delay.

Table 5

Conditional probabilities of a peck for the shorter terminal-link schedule in the four experimental conditions of Experiment 4, given that the last peck was for the shorter schedule ($P_S|_S$) or for the longer schedule ($P_S|_L$).

Bird	Condition	Choice proportion (S)	$P_S\|_L$	$P_S\|_S$	Dependency index[a] ($P_S\|_L$-$P_S\|_S$) Mean	High	Low	Change from baseline
1411	Regular	.70	.77	.67	.10	.16	.06	
	COD 2-sec	.74	.17	.94	−.77	−.77	−.79	−.87
	Regular	.74	.67	.76	−.09	.05	−.24	
	Blackout 2-sec	.76	.37	.86	−.49	−.37	−.57	−.40
7697	Regular	.56	.52	.59	−.07	.00	−.13	
	Blackout 2-sec	.67	.31	.85	−.54	−.50	−.57	−.47
	Regular	.82	.60	.87	−.27	−.10	−.41	
	COD 2-sec	.96	.23	.99	−.76	−.66	−.85	−.49
7598	Regular	.69	.57	.73	−.16	−.07	−.38	
	Blackout 2-sec	.85	.32	.94	−.62	−.58	−.69	−.46
	Regular	.74	.75	.73	.02	.09	−.07	
	COD 2-sec	.98	.43	.98	−.55	−.36	−.85	−.57
859	Regular	.69	.84	.62	.22	.34	.09	
	COD 2-sec	.81	.65	.85	−.20	−.13	−.24	−.42
	Regular	.73	.91	.67	.24	.34	.07	
	Blackout 2-sec	.96	.51	.98	−.47	−.04	−.73	−.71
1405	Regular	.75	.79	.74	.05	.14	.00	
	COD 2-sec	.72	.26	.90	−.64	−.55	−.69	−.69
	Regular	.76	.75	.76	−.01	.04	−.17	
	Blackout 2-sec	.85	.45	.90	−.45	−.32	−.59	−.44

[a]Positive values represent switching dependencies; negative values represent repetition dependencies.

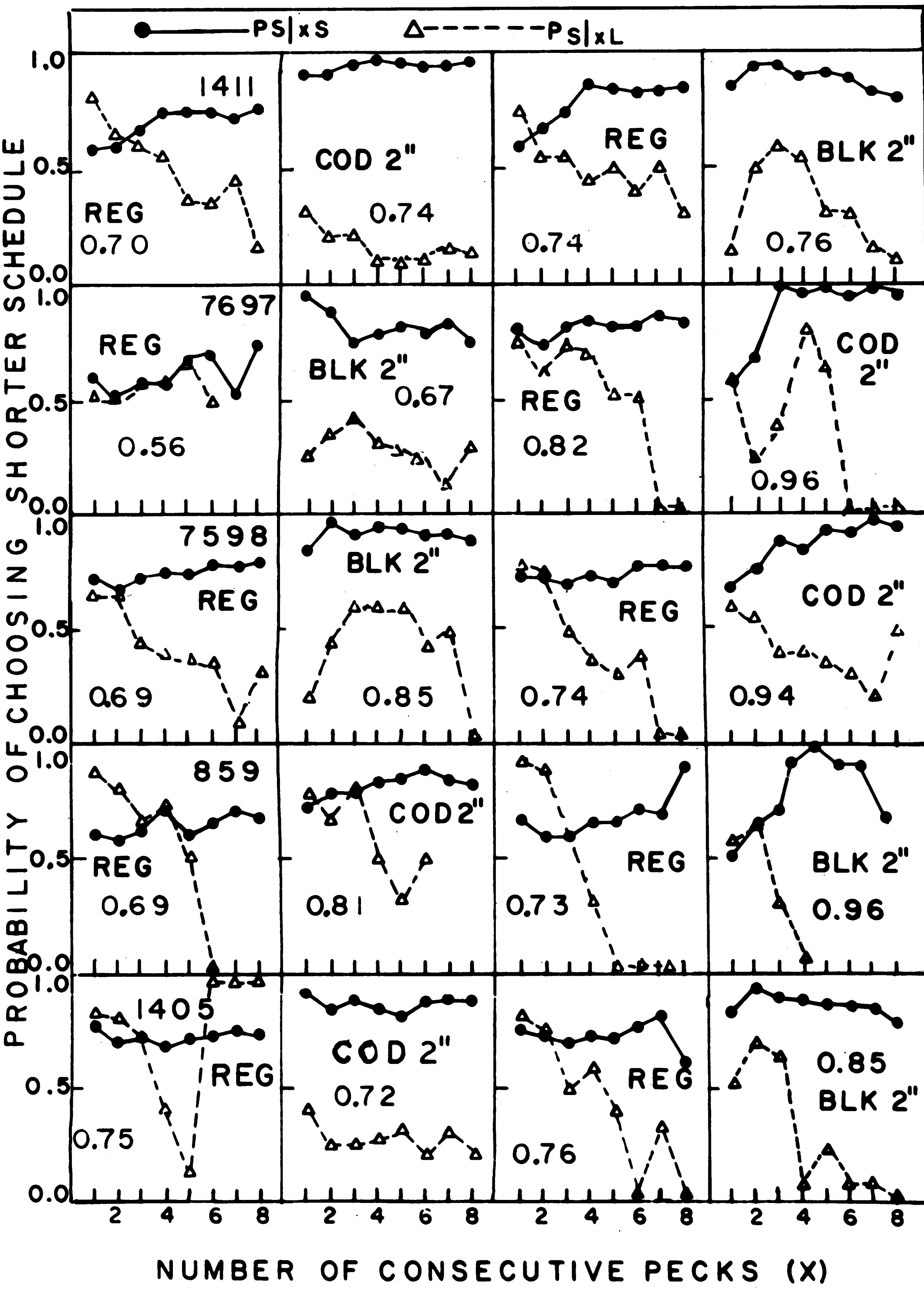

Fig. 6. The conditional probabilities of a peck for the shorter of two terminal-link schedules given X consecutive pecks for the shorter schedule ($P_{S|XS}$) and X consecutive pecks for the longer schedule ($P_{S|XL}$), Experiment 4. The shorter terminal-link schedule was FI 5-sec and the longer was FI 15-sec. Except for this difference between terminal-link schedules, the experimental procedure and method of recording choice probabilities were identical to those of Experiment 3.

GENERAL DISCUSSION

The decision to include or omit a changeover delay in an experiment involving concurrent chained schedules could play a significant role in determining the outcome of the experiment and the conclusions that one draws. A model is usually considered to provide an adequate description of choice in concurrent chains only if theoretical choice proportions closely approximate obtained choice proportions, similarity between the rank orders of these values not ordinarily being regarded as sufficient (Fantino & Navarick, 1974; Navarick & Fantino, 1974, 1976). The usual effect of a changeover delay in simple concurrent schedules is to make choice proportions more extreme (e.g., Herrnstein, 1961; Schroeder & Holland, 1969), and the results of Experiment 4 of the present study suggest that the changeover delay has a similar effect in concurrent chains. Given the potential impact of a changeover delay on choice proportions and the importance of the precise values of choice proportions in the evaluation of models, the need for a systematic rationale for instituting a changeover delay in concurrent chains is particularly acute. A systematic rationale would also be useful in work with simple concurrent schedules because, as noted in the Introduction, inconsistent use of the changeover delay has added a quality of ambiguity to the theoretical implications of some findings.

With simple concurrent schedules, the changeover delay is said to prevent responding on one schedule from coming under the control of the alternate schedule (Catania, 1966; deVilliers, 1977). The sort of control that investigators often conceive is that of a superstitious chain in which the response on one schedule acts as a discriminative stimulus for a response on the other schedule. To assess the degree to which concurrent performances are independent of one another, investigators have traditionally relied on two criteria, neither of which is entirely satisfactory. One criterion is that of orderly variation in the preference measure with changes in the reinforcement parameter under study. For example, Herrnstein (1961) reinforced pecks on concurrent VI schedules both with and without a changeover delay. When a changeover delay was in effect, the proportion of pecks on a key was found to match the proportion of reinforcements on that key; but, when no changeover delay was in effect, the proportion of pecks did not vary appreciably with the proportion of reinforcements. Similar results with human subjects have been obtained by Schroeder and Holland (1969). The problem with this criterion is that it reveals only the grossest interactions between concurrent performances. Orderly data are usually obtainable in concurrent chains without a changeover delay, and, as noted in the Introduction, orderly data have also been obtained without a changeover delay in simple concurrent schedules. The usefulness of the orderly-data criterion is therefore limited.

Another criterion of independence between concurrent performances is that of "rate constancy" (Catania, 1966): pecks on two keys are said to be independent to the extent that the response rate on one key remains constant during alternations between reinforced high rates and unreinforced low rates on the other key. As a practical matter, this criterion is of limited usefulness for monitoring concurrent performances because it requires the introduction of special experimental conditions. Another difficulty is that rate constancies do not rule out the possibility of switching dependencies in the sense that they have been defined here: a lower probability of a peck on a key if the last peck was on that key than if the last peck was on the other key. For example, Catania (1976), without using a changeover delay, reinforced pecks on one key according to a VI 3-min schedule and alternately instituted VI 3-min and extinction on the other key for a number of sessions. The alternations between reinforcement and extinction eventually produced performances on the unchanged key that approached (but generally did not reach) rate constancy. Even if the response rate on the unchanged key had remained constant, switching dependencies would still be a logical possibility under the concurrent VI 3-min VI 3-min schedules.

As a means of assessing the degree of independence between concurrent performances, the dependency index employed here ($P_{L|R} - P_{L|L}$) does not require the introduction of any special experimental conditions, and it is capable of detecting interactions even when choice proportions vary systematically with the independent variable. A substantial value of the dependency index would be sufficient grounds for instituting a changeover delay whatever effect this may have on the precise values of choice proportions. Not only would this procedure be suitable for concurrent chains, but for simple concurrent schedules as well since with the latter paradigm orderly data are obtainable without a changeover delay and one cannot always assume at the outset of an experiment that a changeover delay will be necessary. In experiments involving either paradigm, it may be desirable to assume that no changeover delay will be necessary until evidence of substantial interaction is found.

Changeover Delay or Blackout?

Although the changeover delay is the procedure most often used to reduce the frequency of switching, the present data suggest that a blackout dependent on changeovers may be preferable. Both procedures were found to have the undesirable effect of replacing switching dependencies with strong repetition dependencies, but the blackout procedure tended to maintain greater independence between pecks on a given schedule. In an analysis of the effects of blackouts on local response rates in simple concurrent schedules, Todorov (1971) obtained complementary data suggesting that the blackout procedure may also produce greater independence between pecks on alternate schedules. In his study, pigeons chose between two VI schedules under a changeover-key procedure, with blackouts varying from .3 to 9 sec in duration. It should be noted that both VI timers stopped operating during the blackouts, whereas in the present study the initial-link VI timers continued to operate during the blackouts and the changeover delays. Whether this procedural difference influences responding has not yet been determined (deVilliers, 1977, p. 244). Local response rate was defined as the number of responses on a schedule divided by the amount of time spent in the presence of the stimulus associated with that schedule. When the VI schedules differed in duration (VI 1-min vs. VI 3-min), the relative local rate on the schedule of shorter duration (local rate on the schedule divided by the sum of the local rates on both schedules) was found to increase as the duration of the blackouts increased. In contrast, earlier studies (e.g., Catania, 1966; Stubbs & Pliskoff, 1969) had found that local response rates tended to remain constant with changes in the duration of a changeover delay. In his study, Todorov suggested that, as relative local rate increased, the performances on the two schedules increasingly approximated those that would have been maintained if the schedules had been presented in isolation from one another; in other words, the concurrent performances became increasingly independent. While too little data are presently available to reach any firm conclusions regarding the relative merits of the blackout and changeover delay, there seems to be at least as much justification, and perhaps greater justification, for using the blackout.

Utility of Concurrent Chains

Certain features of the present findings may seem to cast doubt on the advisability of using the concurrent-chains procedure itself in studies of choice. One criterion of the usefulness of any experimental procedure is its stability: data should be recoverable in replications of conditions and should not vary appreciably with minor procedural changes. In the present study, neither aspect of stability was fully exhibited. For example, the seemingly minor procedural variation of introducing a blackout during a 2-sec COD interval had a considerable impact on responding. In Experiment 3, switching dependencies under the free-operant procedure tended to be lower after a changeover delay or blackout condition had been studied than before. Such findings might incline an experimenter to view concurrent chains as a labile procedure unsuitable for establishing generalizations about choice.

It should be emphasized at this point that many significant theoretical insights have emerged from concurrent-chains research during the past decade (Fantino, 1977), and these developments provide ample testimony to the utility of the paradigm. Most previous research has focused on molar aspects of choice, but recent evidence suggests that investigations of molecular processes are also likely to have broad significance as a number of sequential patterns observed here apparently characterize choice under a variety of procedures. Silberberg, Hamilton, Ziriax, and Casey (1978) examined sequential dependencies under two discrete-trial procedures with a 6-sec intertrial interval and unequal reinforcement probabilities on the two keys, and under a concurrent-chains procedure with VI schedules of unequal duration in the terminal links. In both the discrete-trial and free-operant procedures strong switching dependencies occurred. Moreover, as in the present study, the probability of a changeover decreased as the number of consecutive pecks on a key increased, an effect Silberberg et al. referred to as "perseveration." Results of an additional experiment with simple concurrent schedules revealed effects of a changeover delay similar to those found here with concurrent chains. A single VI schedule determined the availability of reinforcement, with reinforcement assigned to one key or the other probabilistically. The changeover delay interval was 1.5 sec. Strong repetition dependencies occurred when reinforcement probabilities on the two keys were either equal or unequal. In addition, the size of these dependencies decreased after the changeover delay interval elapsed, as in Experiment 2 of the present study. In the absence of a changeover delay, results differed from those obtained with the discrete-trial and concurrent-chains procedures: the magnitude of sequential dependencies was generally small and the direction inconsistent across subjects, although there was a slight tendency toward perseveration. Heyman (1979), using a similar method of arranging simple concurrent schedules, also reported a lack of clear sequential dependencies in the absence of a changeover delay. Two general implications of these findings may be noted. First, from a methodological standpoint, it would seem that greater control of factors that influence the emission of response sequences should improve the stability of molar measures of preference, at least in those procedures that generate strong sequential dependencies, as frequent emission of a sequence could substantially affect the proportion of responses on a given key. Second, from a theoretical standpoint, the pervasiveness of switching, repetition, and perseveration dependencies suggests that models of choice which describe these phenomena should realize significant gains in precision and generality.

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